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THE LBL-EPB DATA ACQUISITION SYSTEM: ITS DESCRIPTION AND CONSTRUCTION

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Introduction

This paper presents a description of the microprocessor-controlled data acquisition system used by the Energy Performance of Buildings Group (EPB) at the Lawrence Berkeley Laboratory (LBL). The descriptive material is organized in three sections: the hardware necessary to complete a basic data acquisition system and post-manufacture modifications necessary to make the system work properly; the system programs needed to use the data collection system, and, several implementations of the data logging systems which provide examples of the versatility of the system.

The LBL-EPB data acquisition system has been used at LBL in several research experiments related to energy conservation. In one experiment, the system was used to monitor efficiencies of residential appliances (e.g., fireplace, furnace etc.) using a method called electric co-heating.[1] In another, the system was used to measure the thermal performance of walls in-situ.[2] This experiment involved controlling the temperatures applied to the wall being tested, and data acquisition and reduction to compute the heat flowing through the wall. In a third experiment, the system was used to measure, average, and record temperatures and surface pressures on houses to correlate air infiltration with weather and local terrain in conventional and energy-efficient homes.[3]

Section 1: Hardware

The heart of the EPB data acquisition system is a microcomputer based on the Zilog Z80 microprocessor. As a general purpose microcomputer, we can use the same computer to develop the data collection and reduction programs and to run the data acquisition system itself.

The memory to store the programs and data is contained in two circuit boards. The central processing unit (CPU) board contains the microprocessor and 8k (k=1024) bytes (characters) of read/write memory plus 6k bytes of read-only memory to store the start-up program. There are also 48k bytes of read/write memory on a second board. This memory is logically contiguous with the 8k bytes on the CPU board, to provide a total capacity of 56k bytes. (A description of memory organization is given in Appendix A.)

In addition to the main computer memory, the system has a dual floppy disk drive for the storage of programs and data, which can be retrieved at any time. This magnetic media memory device is approximately 1000 times slower than main memory but can store several times more data per diskette than can main memory.

To facilitate mathematical operations, the system contains a single-board arithmetic-processing unit which can manipulate floating-point numbers quickly and efficiently. Its use reduces software development and cuts processing time for individual functions by a factor of 10 to 25. In addition to the four basic functions (add, subtract, multiply and divide) several transcendental functions are built in, such as $\sin(x)$, $\cos(x)$, $\tan(x)$, e^x, $\backslash|\overline{x}$, $\ln(x)$, $\log(x)$, y^x and the inverse trigonometric functions.

The computer can start data logging without operator intervention by using a timing-control unit (clock) which always has the current date and time accessible to the computer. This clock has battery backup and, if the power fails, will keep the correct date and time for up to three months.

Input and output signals used by the system can be either digital (two-value) or analog (multi-value) voltages or both. For signals such as temperature, heat flux, wind direction etc. that use analog sensors, the analog-to-digital (ADC) board in the system converts the analog voltages to binary numbers. Two-state signals such as switch closures, solenoid valve state, etc. are connected to the digital input port on the computer board itself.

1.1 Hardware Modifications

Several hardware modifications are necessary to allow the components of the system to operate together smoothly. Some are simple option-selection jumpers, one is a more involved circuit modification, and one involves a trace cut and an added wire. Refer to Figures 1, 2, and 3 when making the modifications to the circuit boards described below.

1.1.1 Central Processor Board

Refer to Figure 3 for parts placement and identification of the central processing unit (CPU) board. In the plastic box marked "SERIAL I/O KIT" there are two rather large integrated circuits (IC's). Plug the larger of the two, marked either AM9551 or 8251, into the socket marked (in white paint on the board) "U23". Note: there may be a different prefix (e.g., P or AM) and/or a different suffix (e.g., P, PC or C) on the IC's, but the basic number must be 9551 or 8251. Orient the notch in the end of the IC as shown by the white outline painted on the board. Make sure all pins are in position before pressing the IC into place. After inserting, check to see that none of the pins is bent. If any pin is bent, remove the IC, straighten the pins with pliers and re-insert. The next largest IC in the serial I/O kit is marked 8253 and is plugged into socket U21.

There should be seven more IC's in the box, three small ones with six pins each, and four with 14 pins each. The three small ones and two of the larger ones will not be used in this application. The type of terminal in this application uses the EIA standard RS-232. Most terminals are of this type and therefore can be used with the computer system. The two remaining IC's are labeled MC1488 (or SN75188) and MC1489 (or SN75189). Plug the MC1488 into socket U14 and the MC1489 into socket U15.

So far we have:

IC	Socket
9551 (or 8251)	U23
8253	U21
MC1488	U14
MC1489	U15

Next install the jumpers. These are either blue plastic or gold colored metal, both with holes for posts in one end. To install a jumper, simply place it over the two posts to be connected and press down until contact is made with the board. The posts are square, gold colored posts that stick up from the board about 3/8". For reference purposes, numbers are painted on the board next the posts. These are the numbers that will be referred to in the jumper lists. Install jumpers between the following posts: (use the plastic jumpers)

34-35
38-39
41-42
46-47 (use the three-holed metal jumper)
49-50
118-119

Next, insure that the remaining jumpers are set correctly for the rest of the board. Do the following:

Remove the jumper at 79-80.

Move jumper from 101-102 to 102-103.
Move jumper from 52-53 to 51-52.
Install jumper at 70-72 (use the jumper removed from 79-80).

Be sure that the following jumpers are installed:

57-58
109-110
113-114
81-82
87-88
91-92
107-108
54-55

Check that the following jumpers are not installed:

59-60
111-112
83-84
85-86
89-90
116-117
36-37

Now the IC's for the parallel I/O section must be installed. These are the two large IC's, both labeled AM9555 or 8255 in the two plastic boxes marked "PARALLEL I/O KIT 1". They plug into sockets U20 and U22. For proper operation of the parallel I/O section, refer to section 1.6.2, section 6 and Appendix, section C, Table T7 of the MSC 8001 user's manual for the jumper and IC configuration specific to an application. Basically, the choices are data direction (input, output or both) and positive or negative logic for each I/O port.

For the next jumpers, some 28- or 30-gauge wire is needed along with a wire-wrap tool and wire strippers. Strip 1" of insulation from each end of a 3" piece of wire and wrap from post 63 to post 68. Do the same with another 3" piece of wire and wrap it from post 64 to post 67. Do the same with a 5-1/2" piece and wrap it from post 104 to post 64 over the wrap just completed. Last, strip a piece of 6" wire and wrap it from post 66 to post 96.

The next modification involves cutting a trace in the circuit board and soldering in a new wire. Between IC's U48 and U49 there is a trace (on the top side of the board) with a solder point at both ends, as shown in Figure 1.

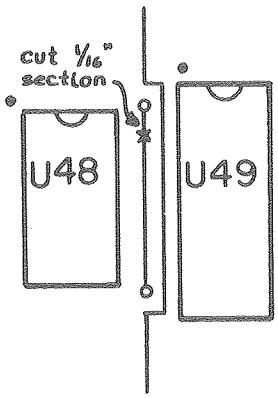
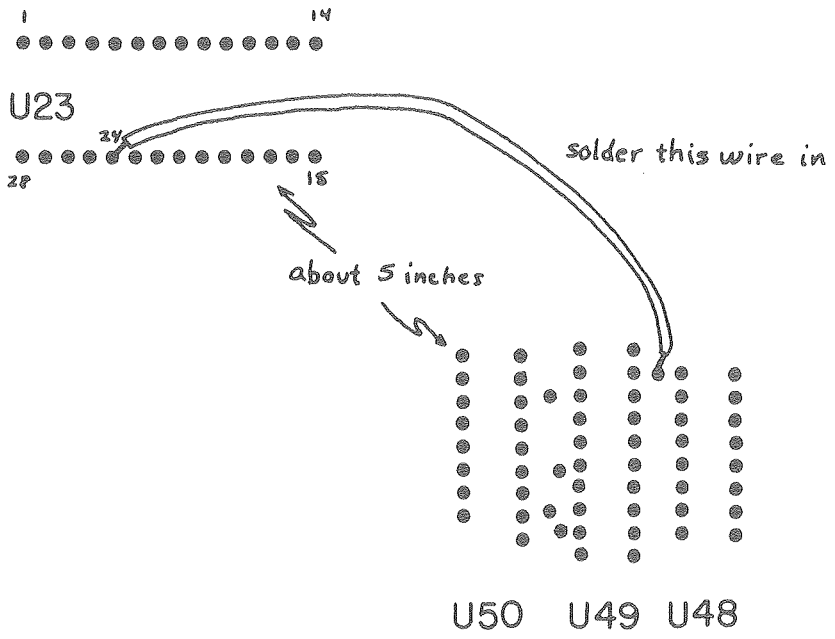


Figure 1. Trace Cut

With an X-Acto blade or scalpel, cut about a 1/16" segment out of the trace between the two solder points (e.g., where it is marked "x" above). Now, strip about 1/16" from each end of a 5-1/2" piece of wire and solder it to the points on the underside of the board as shown in Figure 2.

Figure 2. Wire Jumper



Note: the IC's are not labelled on the underside of the board, but their location can be determined by sighting the IC from the top and turning the board over.

The next step is to remove U49 from its socket and install the IC labelled **0021-017** in white paint in its place. The notch should be oriented the same way as the IC's on either side of U49, as the white outline is not visible for this IC.

Next, program one EPROM according to the listing for the 20k system shown in Appendix D and plug it into socket U39. This EPROM contains the program necessary to load CP/M from the floppy disk.

The final step is to obtain a SN7407 (or equivalent) integrated circuit (not included in the package) and replace U35 with it.

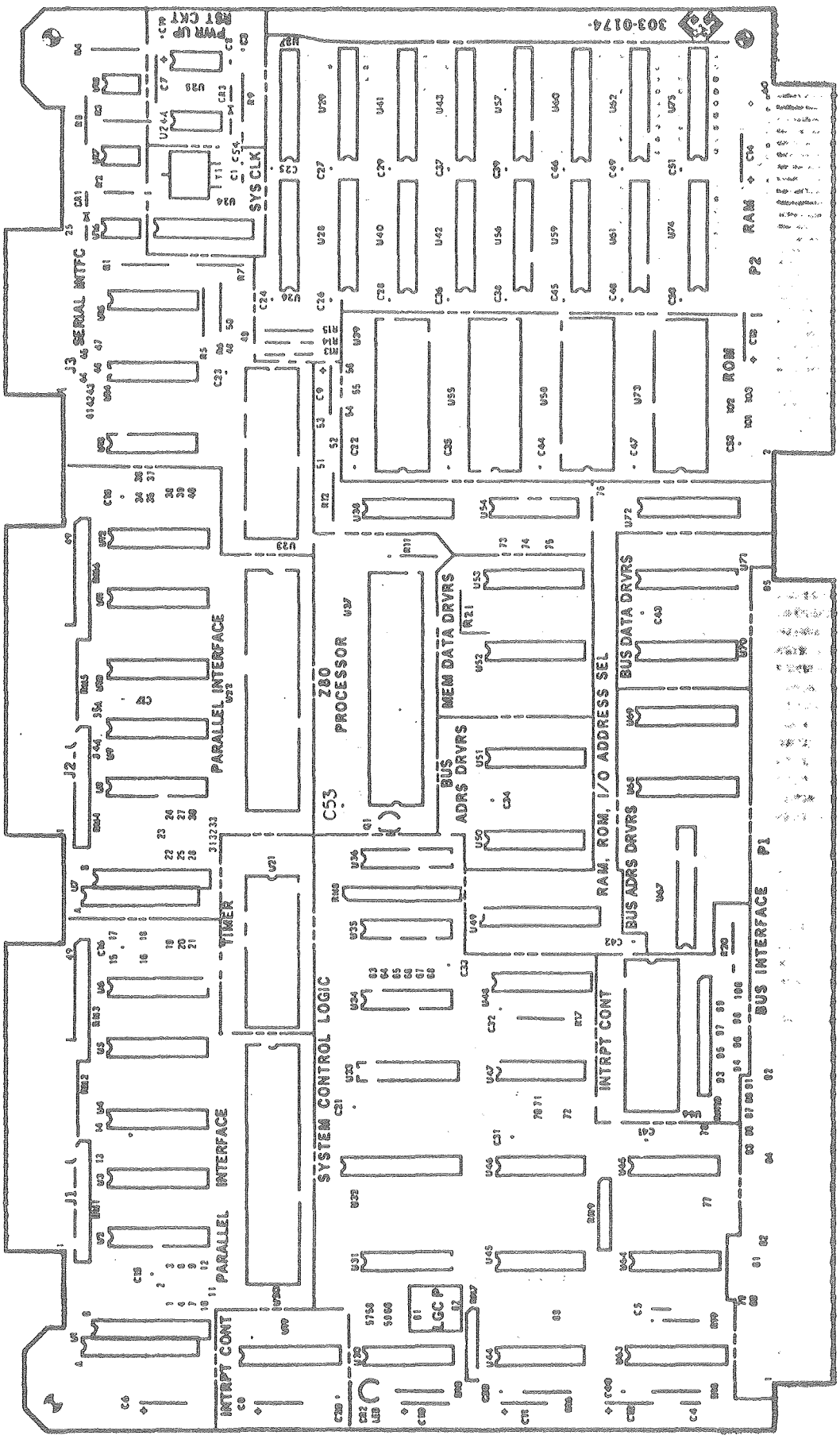


Figure 3. CPU Board

1.1.2 Memory Board

The MSC 4602 memory board is much simpler to modify. The first change needed to make it work properly is to remove the jumper from posts 55-56 and insert post 54 to post 55. This procedure requires a piece of 3" wire stripped at both ends and wire-wrapped on the posts. The next change is to slide switches 1 through 8 on SW2 all to the "on" position (see the MSC 4602 memory board manual, p.14, for the location of these switches). The "on" direction is toward the edge connector of the board. On switch bank SW1, slide switches 1, 3, 4 and 6 "on", and 2, 5, 7 and 8 "off". This completes the memory board.

1.1.3 Analog to Digital/Digital to Analog Board

The Analog Devices Inc. RTI 1200 ADC/DAC board requires a few simple solder jumpers and some wire-wrap jumpers for proper operation. Refer to the RTI 1200 manual page 6-3 for the location of programming socket X1. Either a DIP switch or a DIP header, both of which are described in the hardware list in Appendix B, may be used to select the board memory base address. If the DIP switch is used, plug it into socket X1 so that switch 1 is closest to the "X1" printed on the board. Turn on switches 1 through 4 and turn off 5 through 8. If a DIP header is used, solder a wire across each of the first four pairs of contacts and plug it into socket X1 so that the wires are closest to the "X1" on the board. These jumpers put the base address of the board at FFF0 hexadecimal (hex) through FFFF hex. Refer to the manual, page 11-3, for the exact memory address of each register. Holes 67 and 68 must be connected together with a short (3/8") piece of solid, 26-gauge (approx.) wire that is then soldered in place. Holes 86 and 87 are to be connected in the same manner.

For the rest of the jumpers, refer to page 12-16 of the manual where the jumpers and their functions are listed, along with reference pages providing a more complete description.

1.1.4 Arithmetic Processing Unit Board

The Digital Pathways Inc. Timing control unit TCU 410 board comes configured for I/O port addresses, A0 hex through A6 hex. This is indicated with a silver label saying "Adr-AX". If it does not say this, refer to the manual (page 6) to find out how to set the board to addresses A0 through A6.

1.2 Putting It All Together

Before putting the units in the rack, the power supply must be checked out. Refer to the MSC 8202 microcomputer power supply manual for initial checkout and adjustments. Do not do the load test yet; that requires that it be connected to the computer. The units may now be mounted into the rack. The power supply should be put lowest in the rack because it weighs more than the card cage. The power supply and card cages can be attached to the rack by their face plates and some 10-32 round-head or pan-head machine screws. For a neater look, use 10-32 oval-head machine screws with countersunk finishing washers. The computer card cage should be placed above the power supply in the rack. After securing the cage, connect the two cables on the power supply marked "J10" and "J11" to their respective connectors on the back of the computer card cage. Be sure to orient them so that the plug in the cable connector matches with the missing pin on the card cage connector. Next, connect one of the black cords on the power supply (not the power cord) to the fan on the card cage. Next, mount the 40 connector card cage and, on top of that, the floppy disk drive. The disk drive is the heaviest unit in the system, but it should be up high to be easily accessible and out of the way of foot traffic.

The circuit boards may now be plugged into the computer card cage. Slide the memory board in between the plastic guides on the bottom slot and press on the plastic handles until it is securely in the connector at the back of the card cage. Next, reach from behind and slide the terminal cable through the cutout in the card cage to the front. While holding on to it, slide the CPU card in the third slot up to leave room,

and plug in the terminal cable. The cable should plug in so that the wires come up from under the board. Next, plug in the arithmetic board and the clock board. (The slots are all the same, so they may be plugged in anywhere, but leave the top slot for the disk drive interface.) Now bring the disk drive cable (flat ribbon cable) in the card cage from the back as with the terminal cable and, while holding on to it, plug in the disk interface board in the top slot. Now plug in the cable to the 50-pin connector on the interface board, matching the arrows embossed on both connectors.

The disk drive and power supply power cords may now be plugged in to the power strip in the rack. Connect the computer terminal to the cable from the computer board with a similar cable and turn on the terminal. Place the CP/M diskette in the left-hand drive (drive A or 0) and turn on the drives. Set the speed on the terminal to 300 baud (30 characters per second) and turn on the computer power supply. The terminal should respond with the message **"CPM 2.0"** followed by a delay while the disk is being read, after which the prompt **"A>"** should appear. If this occurs you have a working computer! At this point you should refer to the CP/M 2.0 user's manual to learn the operation of CP/M.

When you are sure that CP/M is working according to the manual, the system may be enlarged from 20k to 56k. To do this, first program the second EPROM according to the listing for the 56k system in Appendix D. Next, in CP/M, type the command **"MOVCPM 56 *"**. Be sure to type the asterisk as shown. MOVCPM should respond with the following:

```
CONSTRUCTING 56k CP/M VERS 2.0
READY FOR "SYSGEN" OR
"SAVE 34 CPM56.COM"
A>
```

Now place a blank disk in drive B (right-hand drive). Type the command "SYSGEN" and respond to the following interaction according to the text in parentheses:

```
SYSGEN VERSION 2.0
SOURCE DRIVE NAME (OR RETURN TO SKIP)
```

(Respond with a carriage return to skip the read operation since the system is already

in memory.)

DESTINATION DRIVE NAME (OR RETURN TO REBOOT)

(Respond with "B" to write the new system on the disk in drive B)

DESTINATION ON B, THEN TYPE RETURN

(Hit return key to perform the write)

FUNCTION COMPLETE

DESTINATION DRIVE NAME (OR RETURN TO REBOOT)

(Hit return to bootstrap the system)

There is now a 56k system on the disk in drive B. Next, turn off the computer and remove the CPU board. Remove the EPROM in socket U39 and replace it with the EPROM programmed with the 56k system. Replace the CPU card in the chassis. Remove the original CP/M disk from drive A and set aside. Remove the disk from drive B, put it in drive A and turn the computer on. The system will respond with the message "CP/M 2.0" and again, the prompt "A>". You now have a 56k system. Follow the directions in the CP/M system alteration manual to generate systems on other disks.

Section 2: System Software Description

This section describes some of the software necessary to develop programs for the data acquisition system.

2.1 The Disk Operating System (CP/M)

The floppy disk drive is organized as 2,002 blocks of storage, on 77 tracks of 26 blocks each. In order to manage information as files instead of blocks of data, the CP/M* disk operating system is used. This program keeps track of data by keeping file names and information about the location of files on the disk. To the user, a file is simply a stream of characters sequentially accessed for a serial file or an array of records (any size) for a random-access file. The programmer doesn't need to know where to look on the disk for a file or where to get more disk space to enlarge a file; CP/M manages these requirements.

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* CP/M, MAC and ED are registered trademarks of Digital Research Corp.

2.2 Utility Programs

Basic-80** is a computer language that allows one to write algorithms and control programs (such as data logging) in quasi-English form. It interfaces with CP/M to give the user full disk-file access for both random-access and sequential files. It has a floating-point math package of its own to allow numbers ranging from -10^{38} to 10^{38} with 7 digits of precision for single-precision numbers and 16 digits for double-precision numbers.

The macro assembler, MAC, allows the user to assemble 8080 and Z80 symbolic instructions (assembly language) into machine-ready code.

When choosing between assembly language and Basic for program design, there are several tradeoffs to consider. In general, a program written in assembly language will be many times faster (10-100 times) than the same one written in Basic, but it takes longer to write and to remove errors. On the other hand, the speed of data acquisition using Basic is limited to one or two readings per second. For higher rates, assembly language must be used.

The editor, ED, is a general-purpose text editor which is used for generating and correcting assembly language programs before assembling them with the macro assembler. ED may also be used to edit Basic programs when complex changes are required.

** Basic-80 is a registered trademark of Microsoft Corp.

Section 3: Several Implementations of Data Collection Systems

This section gives an overview of some of the concepts used in designing data collection systems with the LBL-EPB data acquisition computer system.

3.1 Measurement of Residential Energy Performance

In one application of the LBL-EPB data acquisition system, the energy performance of residential homes was measured using a method called electric co-heating[1]. In this experiment the computer measured indoor and outdoor temperatures, averaged them every five seconds, controlled eight 1.3kW electric heaters, measured the power consumption of those heaters along with total-house power consumption, and read the concentration of a tracer gas used to compute the infiltration rate. All of the data were stored on the floppy disk for later analysis.

The temperature sensor signals were conditioned with operational amplifiers (op-amps) on circuit cards that plugged into the 40-slot card cage. These signals connect to the ADC board. The power consumption of the heaters and the house were monitored with modified watt-hour meters. These meters have an optical sensor mounted on the rotating disk which produces a pulse when a black strip painted on the disk passes by the sensor. The rate of the pulses determine the rate of power consumption. The concentration of the tracer gas was measured by a gas analyzer with its output fed into the computer via the ADC board.

The bulk of the program was written in Z80 assembly language. This includes the heater control, all measurements, and logging of data on the disks. A Basic program ran in the background (while the system was collecting data) to allow the operator to change parameters, cycle schedules, etc., and to look at intermediate data when needed. This is a good example of a data acquisition application where Basic was mixed with assembly language.

The program was written in logically separate sections called tasks. A task is defined as a procedure that the computer follows to effect an operation (e.g., read and average temperature sensors). The tasks run at specified intervals determined by the programmer (e.g., five seconds between sampling the sensors), and the actual scheduling of the tasks is done by a multi-tasking executive called Torx-80 .[4]

3.2 Testing Thermal Performance of Walls In-situ

In the Envelope Thermal Test Unit (ETTU) the LBL-EPB data acquisition system was used to analyze the thermal resistance and dynamic response of walls in existing homes[2]. The unit consists of two identical "blankets" which are placed in close thermal contact with the wall to be tested. Each blanket consists of a pair of large-area electric heaters separated by a low-thermal-mass insulating layer. Embedded in each heater layer is an array of temperature sensors. The computer is used to drive the system and record the system temperature responses by generating pseudo-random numbers at regular intervals to control the primary drive heaters. As the data are accumulated the computer also calculates a Fourier transform of the data streams to determine the response of the wall to heat flow. This program also uses Torx-80 to schedule the tasks.

3.3 Measuring Infiltration in Conventional and Energy-Efficient Homes[3]

In comparing air infiltration and leakage between conventional and energy-efficient homes, the data acquisition system was used to monitor the local weather conditions and surface air pressures on the particular house. The air pressure was sampled at seven locations around the outside walls, in the crawl space, and on the roof - each at a rate of 40 times per second (40 Hz). The data was digitally filtered so that vibrations in the air lines would not affect the data, and averaged over a period of an hour. The wind speed, wind direction and outside temperature were all measured every 10 seconds using equipment mounted on a 10-meter high weather tower. The data were averaged each hour and recorded on the disk with the air pressure data.

The preceding examples are given to provide the reader with an idea of the range of capabilities of the LBL-EPB data acquisition system, from simple data sampling and logging to Fourier analysis and system control.

Acknowledgement

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Appendix A: Memory Organization

Figure 4 shows the hardware configuration of the memory space as seen by the computer. To the user, the ROM space from ROM 1 (address E000 to E7FF hex) to ROM 3 (address F000 to F7FF hex) appears to be contiguous read-only memory. In the same way, the read-write memory space from CPU RAM (0000 or 0800 hex to 1FFF hex) to the end of the 4602 memory board space (DFFF hex) appears to be a contiguous area of read-write memory.

Two memory configurations ("maps") are used in the computer system. The first is enabled when power to the computer is turned on or the reset button is pressed, as shown in map 1 of Figure 4. In this configuration, ROM 1 appears both at addresses 0000-07FF hex and E000-E7FF hex. This is because the microprocessor starts executing instructions at address 0000. The program to load CP/M from the disk is located in ROM 1 so that it isn't erased when the power is turned off. Its first instruction is a "jump" to a location in the other copy of ROM 1, at E000 hex. In the sequence of instructions that follow, the program switches to memory map 2 (normal operation) where the read-only memory at address 0000 is replaced by read-write memory (see Figure 4). This method of loading a system is often called "ROM shadowing".

For a 56k system, CP/M is loaded into memory starting at address C400 hex. This is the largest system size possible with 56k of read-write memory - the amount in the LBL-EPB computer system. The first section loaded from disk is called the console command processor (CCP). (Refer to the CP/M user's manual for a complete description of CP/M.) The next section, the basic disk operating system (BDOS) is loaded at address CC06. The last section, the basic I/O system (BIOS) starts at address D200 hex. This is loaded from ROM 1 when the computer is turned on or when the reset button is pressed.

Most programs run under CP/M load in what is called the transient program area (TPA) at address 0100 hex. The program may use memory from 0100 hex to CC05 hex; in other words, it may overwrite the CCP while it is executing because that part of CP/M is used only for accepting

commands from the user; not when a user program is executing. The user program can also make calls to the BDOS to do file operations and other I/O.

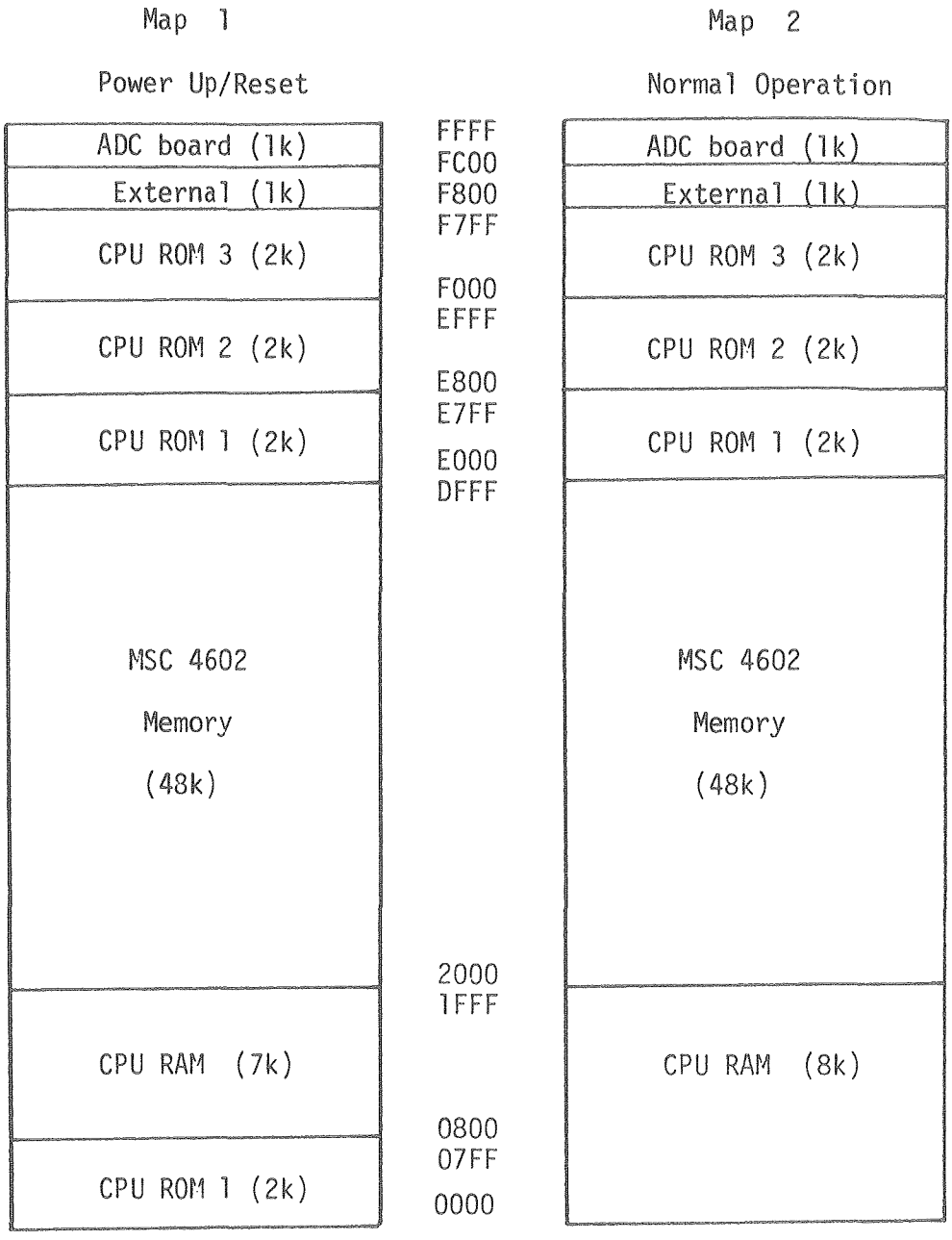

Figure 4. Hardware Memory Organization

Appendix B: Hardware List

1) Monolithic Systems Inc. MSC 8001 CPU board:
   Z80A Microprocessor
   8255 Parallel I/O (2)
   8k RAM (read/write memory)
   0021-017 Memory Map PROM (U49) (be sure to specify this part)

2) Monolithic Systems MSC 4602 RAM board with 48k installed.

3) Monolithic Systems MSC 8202 power supply.

4) Monolithic Systems MSC 8201 card cage.

5) Control Logic Corp. 40-connector system card cage assembly, without connectors.

6) Viking Inc. Type 2MH22/1AN5 or Masterite Corp. Type S014GR22-DR-H-X-3.596 or equivalent 44-contact printed circuit card connecter with 0.156 in. centers.

7) 2 each Intel 2716 EPROMs or Texas Instruments 2516 EPROMs or equivalent. These EPROMS must be programmed with the data in Appendix D.

8) Advanced Micro Computers AMC 95/6011 arithmetic processing board.

9) Analog Devices RTI 1200 analog-to-digital board.

10) Digital Pathways Inc. TCU-410 timing control unit.

11) Icom-Pertec Dual floppy disk drive FD3712-11-19 with interface for SBC Multibus.

12) Lear Siegler Industries ADM-3A Crt terminal and/or Teletype Corp Model 43 terminal.

13) Bud Radio Inc. equipment rack model CR-2074-HG, 46-1/16 in. high by 22-1/8 in. deep.

14) Robinson Nugent Inc. DIP header Type MPB-163 or equivalent, or Grayhill Inc. DIP switch Type 76A08 or equivalent.

15) 26-wire flat-ribbon cable with T&B Ansley DB-25S connector or equivalent on one end and 3M Corp. Type 3462-0000 26 contact connector or equivalent on the other. This is the cable for the computer terminal.

Appendix C: Software List

1) CP/M 2.0 (r) from Digital Research Corp. This is the disk operating system. It includes the editor, a simple assembler and debugger, and other useful utility programs for file handling.

2) MAC (r) from Digital Research Corp. This is the macro assembler.

3) SID (r) from Digital Research Corp. This is the symbolic instruction debugger.

4) Basic-80 (r) Interpreter from Microsoft Corp. This is the Basic interpreter. The compiler may be purchased to compile programs, once they work.

Appendix D: Hexadecimal Listings of the System Load EPROMs

Listing for 20k system size:

```
0000 F3 31 F0 DF C3 25 E0 00 F3 31 F0 DF C3 73 E0 00
0010 C3 CC E2 C3 CC E2 C3 D8 E2 C3 D8 E2 C3 50 E1 C3
0020 66 E1 C3 AA E1 CD 47 E0 01 E5 E2 CD 50 E1 21 00
0030 E4 11 00 4A 01 50 03 ED B0 3E C3 32 66 00 21 08
0040 E0 22 67 00 C3 03 4A 3E 01 D3 ED D3 BD 3E 40 D3
0050 ED D3 BD 3E 4E D3 ED D3 BD 3E 27 D3 ED D3 BD 3E
0060 B6 D3 DF 21 A0 01 3E 37 D3 ED D3 BD 7D D3 DE 7C
0070 D3 DE C9 F3 31 F0 DF 01 EF E2 CD 50 E1 31 F0 DF
0080 CD 66 E1 0E 2A CD 16 E0 CD 6F E1 FE 0D CA 7D E0
0090 FE 47 CA B8 E0 FE 49 CA BF E0 FE 52 CA AC E0 FE
00A0 57 CA CD E1 0E 3F CD 16 E0 C3 7D E0 CD F6 E0 22
00B0 F4 DF CD 66 E1 C3 49 E2 CD F6 E0 CD 66 E1 E9 CD
00C0 F6 E0 CD 66 E1 CD DB E0 17 17 17 17 E6 F0 47 CD
00D0 DB E0 B0 77 23 C3 C5 E0 CD 66 E1 CD 6F E1 4F CD
00E0 79 E1 D0 79 FE 1B CA 7D E0 FE 0D CA D8 E0 FE 20
00F0 CA DB E0 C3 A4 E0 16 00 62 6A CD 6F E1 4F FE 1B
0100 CA A4 E0 FE 0D CA 22 E1 FE 2C CA 22 E1 FE 20 CA
0110 22 E1 CD 79 E1 DA F6 E0 14 29 29 29 29 85 6F C3
0120 FA E0 7A B7 CA 2A E1 16 00 C9 14 C9 CD 66 E1 4C
0130 CD AA E1 4D CD AA E1 0E 20 C3 16 E0 06 04 17 0E
0140 30 D2 45 E1 0C CD 16 E0 CD 37 E1 05 C2 3E E1 C9
0150 F5 C5 E5 0A B7 CA 62 E1 C5 4F CD 16 E0 C1 03 C3
0160 53 E1 E1 C1 F1 C9 C5 01 05 E3 CD 50 E1 C1 C9 C5
0170 CD 10 E0 4F CD 16 E0 C1 C9 79 D6 30 D8 C6 E9 D8
0180 C6 06 F2 88 E1 C6 07 D8 C6 0A B7 C9 C5 79 CD 9A
0190 E1 4F CD 9F E1 C1 47 C3 9F E1 07 07 07 07 C9 79
01A0 E6 0F C6 30 FE 3A F8 C6 07 C9 C5 F5 CD 8C E1 48
01B0 CD 16 E0 4F CD 16 E0 F1 C1 C9 C5 F5 79 82 57 CD
01C0 8C E1 48 CD 16 E0 4F CD 16 E0 F1 C1 C9 CD F6 E0
01D0 E5 CD F6 E0 EB E1 CD 66 E1 CD DF E1 C3 7D E0 DB
01E0 EC 7B 95 5F 7A 9C 57 D8 13 0E 5F CD 16 E0 D5 01
01F0 10 00 7B 91 5F 7A 98 57 D2 02 E2 C1 11 00 00 C3
0200 04 E2 33 33 D5 CD 20 E2 0E 00 CD BA E1 4E CD BA
0210 E1 23 05 C2 0D E2 CD 2F E2 D1 7B B2 C2 E9 E1 C9
0220 16 00 41 CD BA E1 4C CD BA E1 4D CD BA E1 C9 AF
0230 92 4F CD BA E1 CD 66 E1 7A B3 C8 CD 10 E0 FE 1B
0240 CA 7D E0 FE 11 C2 3B E2 C9 CD 10 E0 FE 3A CA 56
0250 E2 FE 5F C2 49 E2 16 00 CD 8F E2 47 CD 8F E2 67
0260 CD 8F E2 6F 4A EB 2A F4 DF 19 58 51 CD 8F E2 CD
0270 B3 E2 CD 8F E2 77 23 1D C2 72 E2 CD 8F E2 7A B7
0280 CA 49 E2 01 08 E3 CD 50 E1 CD 66 E1 C3 49 E2 C5
0290 CD 10 E0 4F CD 79 E1 DA C6 E2 CD 9A E1 47 CD 10
02A0 E0 4F CD 79 E1 D2 BF E2 CD AD E2 C1 C9 01 17 E3
02B0 C3 50 E1 FE 01 C0 7B B7 C0 CD AD E2 C3 7D E0 B0
02C0 4F 82 57 79 C1 C9 CD AD E2 C3 49 E2 DB ED E6 02
02D0 CA CC E2 DB EC E6 7F C9 F5 DB ED E6 01 CA D9 E2
02E0 79 D3 EC F1 C9 0D 0A 43 50 4D 20 32 2E 30 00 0D
02F0 0A 4C 42 4C 20 5A 38 30 20 4D 69 6E 69 2D 4D 6F
0300 6E 69 74 6F 72 0D 0A 00 43 68 65 63 6B 73 75 6D
0310 20 45 72 72 6F 72 00 0D 0A 45 4F 46 20 4F 52 20
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0320 42 41 44 20 48 45 58 00 FF FF FF FF FF FF FF FF
0330 FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
0340 FF FF 03 41 43 4B 06 00 03 41 4C 30 F0 00 03 41
0350 4C 31 00 00 05 41 4C 4C 30 30 8D DB 05 41 4C 4C
0360 30 31 F8 DB 05 41 4C 4C 30 32 63 DC 05 41 4C 4C
0370 30 33 CE DC 05 41 4C 4C 30 34 39 DD 05 41 4C 4C
0380 30 35 A4 DD 05 41 4C 4C 30 36 0F DE 05 41 4C 4C
0390 30 37 7A DE 05 41 4C 4C 30 38 E5 DE 05 41 4C 4C
03A0 30 39 04 DF 05 41 4C 53 49 5A 6B 00 02 42 43 00
03B0 00 05 42 44 49 53 4B 00 D7 04 42 44 4F 53 06 C4
03C0 03 42 45 4C 07 00 05 42 45 58 49 54 5D D3 04 42
03D0 49 41 53 00 88 04 42 49 4F 53 00 D2 03 42 4C 4D
03E0 0F 00 05 42 4C 4F 4F 50 18 D3 05 42 4F 4F 54 45
03F0 03 D2 04 42 4F 4F 54 00 D3 03 42 53 48 04 00 03
0400 C3 ED 4A C3 8B 4A C3 33 4B C3 3B 4B C3 46 4B C3
0410 59 4B C3 7A 4B C3 7D 4B C3 A6 4B C3 90 4B C3 A8
0420 4B C3 AD 4B C3 B2 4B C3 BE 4B C3 EE 4B C3 51 4B
0430 C3 B8 4B 53 4A 00 00 00 00 00 00 4A 4D 6D 4A 08
0440 4E CA 4D 53 4A 00 00 00 00 00 00 4A 4D 7C 4A 18
0450 4E E9 4D 01 07 0D 13 19 05 0B 11 17 03 09 0F 15
0460 02 08 0E 14 1A 06 0C 12 18 04 0A 10 16 1A 00 03
0470 07 00 F2 00 3F 00 C0 00 10 00 02 00 1A 00 03 07
0480 00 F2 00 3F 00 C0 00 10 00 02 00 31 00 01 0E 00
0490 CD 90 4B CD 80 4B 06 2C 0E 05 16 01 1E 1A 21 00
04A0 33 D5 C5 E5 CD AD 4B E1 E5 EB 26 00 69 29 29 29
04B0 29 29 29 29 19 22 41 00 CD BE 4B B7 C2 8B 4A E1
04C0 C1 3E 04 81 4F 05 CA EC 4A D1 7B B9 D2 A1 4A 14
04D0 4A 3E 04 BA D2 A1 4A 3E 01 32 C2 4C 57 4F 3E 1A
04E0 B8 DA E5 4A 78 5F 21 00 40 C3 A1 4A D1 3E C3 32
04F0 00 00 21 03 4A 22 01 00 01 80 00 CD B2 4B AF 32
0500 07 34 3E C3 32 05 00 21 06 3C 22 06 00 3A C7 4C
0510 B7 CA 2C 4B AF 32 C7 4C 32 04 00 3A C8 4C 32 07
0520 34 4F 06 00 21 C9 4C 11 08 34 ED B0 3A 04 00 4F
0530 C3 00 34 DB ED E6 02 C8 3E FF C9 CD 33 4B CA 3B
0540 4B DB EC E6 7F C9 DB ED E6 01 CA 46 4B 79 D3 EC
0550 C9 DB BD E6 01 C8 3E FF C9 CD 6F 4B FE 0D C0 C5
0560 0E 05 CD 6F 4B DB BD E6 02 28 FA DB BC C1 C9 DB
0570 BD E6 01 CA 6F 4B 79 D3 BC C9 C3 46 4B 3E 1A C9
0580 3E 01 D3 07 3E 21 CD 63 4C 3E 0D CD 63 4C 18 16
0590 21 00 00 79 FE 02 D0 32 40 00 6F 26 00 29 29 29
05A0 29 11 33 4A 19 C9 0E 00 79 32 C2 4C C9 79 32 C4
05B0 4C C9 69 60 22 41 00 C9 EB 09 6E 26 00 C9 CD 28
05C0 4C C2 22 4C 06 0A 3E 03 CD 63 4C CA D5 4B 05 C2
05D0 C6 4B C3 22 4C 2A 41 00 06 80 3E 40 D3 06 DB 07
05E0 77 23 3E 41 D3 06 05 C2 DA 4B AF D3 06 C9 CD 28
05F0 4C C2 22 4C DB 07 CB 67 C2 A2 4C 2A 41 00 06 80
0600 7E 23 D3 07 3E 31 CD 63 4C 05 C2 00 4C 06 08 3E
0610 05 CD 63 4C 3E 07 CD 63 4C DB 07 E6 08 C8 05 C2
0620 0F 4C CD 61 4C 3E 01 C9 3E 0B D3 06 AF D3 06 DB
0630 07 CB 77 3E 00 CC 63 4C 3A 40 00 0F 0F 47 3A C4
0640 4C B0 D3 07 3E 21 CD 63 4C 3A C2 4C FE 4D 30 69
0650 D3 07 3E 11 CD 63 4C 3E 09 CD 63 4C 3E 09 C3 63
0660 4C 3E 0B F5 D3 06 AF D3 06 DB 07 CB 6F C2 87 4C
0670 CB 77 CA 80 4C CB 47 C2 69 4C F1 DB 07 CB 5F C9
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0680 C5 01 16 4D C3 8B 4C C5 01 D3 4C CD 1C E0 CD 3B
0690 4B FE 03 CA 8B 4A CD 1F E0 3E 0B D3 06 C1 F1 C3
06A0 63 4C C5 01 E7 4C CD 1C E0 CD 3B 4B 4F CD 46 4B
06B0 FE 59 C1 CA EE 4B C3 22 4C 01 2C 4D CD 1C E0 C3
06C0 22 4C 00 00 00 00 00 01 0A 53 50 45 45 44 20 39
06D0 36 30 00 0D 0A 07 43 6C 6F 73 65 20 44 72 69 76
06E0 65 20 44 6F 6F 72 00 0D 0A 07 57 72 69 74 65 20
06F0 50 72 6F 74 65 63 74 65 64 2C 20 52 65 74 72 79
0700 3F 20 00 0D 0A 07 49 6C 6C 65 67 61 6C 20 44 72
0710 69 76 65 0D 0A 00 0D 0A 07 54 75 72 6E 20 6F 6E
0720 20 44 69 73 6B 20 44 72 69 76 65 00 0D 0A 07 49
0730 6C 6C 65 67 61 6C 20 74 72 61 63 6B 20 73 65 65
0740 6B 20 28 3E 37 36 29 0D 0A 00
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Listing for 56k system size:

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0000  F3 31 F0 DF C3 25 E0 00 F3 31 F0 DF C3 73 E0 00
0010  C3 CC E2 C3 CC E2 C3 D8 E2 C3 D8 E2 C3 50 E1 C3
0020  66 E1 C3 AA E1 CD 47 E0 01 E5 E2 CD 50 E1 21 00
0030  E4 11 00 DA 01 50 03 ED B0 3E C3 32 66 00 21 08
0040  E0 22 67 00 C3 03 DA 3E 01 D3 ED D3 BD 3E 40 D3
0050  ED D3 BD 3E 4E D3 ED D3 BD 3E 27 D3 ED D3 BD 3E
0060  B6 D3 DF 21 A0 01 3E 37 D3 ED D3 BD 7D D3 DE 7C
0070  D3 DE C9 F3 31 F0 DF 01 EF E2 CD 50 E1 31 F0 DF
0080  CD 66 E1 0E 2A CD 16 E0 CD 6F E1 FE 0D CA 7D E0
0090  FE 47 CA B8 E0 FE 49 CA BF E0 FE 52 CA AC E0 FE
00A0  57 CA CD E1 0E 3F CD 16 E0 C3 7D E0 CD F6 E0 22
00B0  F4 DF CD 66 E1 C3 49 E2 CD F6 E0 CD 66 E1 E9 CD
00C0  F6 E0 CD 66 E1 CD DB E0 17 17 17 17 E6 F0 47 CD
00D0  DB E0 B0 77 23 C3 C5 E0 CD 66 E1 CD 6F E1 4F CD
00E0  79 E1 D0 79 FE 1B CA 7D E0 FE 0D CA D8 E0 FE 20
00F0  CA DB E0 C3 A4 E0 16 00 62 6A CD 6F E1 4F FE 1B
0100  CA A4 E0 FE 0D CA 22 E1 FE 2C CA 22 E1 FE 20 CA
0110  22 E1 CD 79 E1 DA F6 E0 14 29 29 29 29 85 6F C3
0120  FA E0 7A B7 CA 2A E1 16 00 C9 14 C9 CD 66 E1 4C
0130  CD AA E1 4D CD AA E1 0E 20 C3 16 E0 06 04 17 0E
0140  30 D2 45 E1 0C CD 16 E0 CD 37 E1 05 C2 3E E1 C9
0150  F5 C5 E5 0A B7 CA 62 E1 C5 4F CD 16 E0 C1 03 C3
0160  53 E1 E1 C1 F1 C9 C5 01 05 E3 CD 50 E1 C1 C9 C5
0170  CD 10 E0 4F CD 16 E0 C1 C9 79 D6 30 D8 C6 E9 D8
0180  C6 06 F2 88 E1 C6 07 D8 C6 0A B7 C9 C5 79 CD 9A
0190  E1 4F CD 9F E1 C1 47 C3 9F E1 07 07 07 07 C9 79
01A0  E6 0F C6 30 FE 3A F8 C6 07 C9 C5 F5 CD 8C E1 48
01B0  CD 16 E0 4F CD 16 E0 F1 C1 C9 C5 F5 79 82 57 CD
01C0  8C E1 48 CD 16 E0 4F CD 16 E0 F1 C1 C9 CD F6 E0
01D0  E5 CD F6 E0 EB E1 CD 66 E1 CD DF E1 C3 7D E0 DB
01E0  EC 7B 95 5F 7A 9C 57 D8 13 0E 5F CD 16 E0 D5 01
01F0  10 00 7B 91 5F 7A 98 57 D2 02 E2 C1 11 00 00 C3
0200  04 E2 33 33 D5 CD 20 E2 0E 00 CD BA E1 4E CD BA
0210  E1 23 05 C2 0D E2 CD 2F E2 D1 7B B2 C2 E9 E1 C9
0220  16 00 41 CD BA E1 4C CD BA E1 4D CD BA E1 C9 AF
0230  92 4F CD BA E1 CD 66 E1 7A B3 C8 CD 10 E0 FE 1B
0240  CA 7D E0 FE 11 C2 3B E2 C9 CD 10 E0 FE 3A CA 56
0250  E2 FE 5F C2 49 E2 16 00 CD 8F E2 47 CD 8F E2 67
0260  CD 8F E2 6F 4A EB 2A F4 DF 19 58 51 CD 8F E2 CD
0270  B3 E2 CD 8F E2 77 23 1D C2 72 E2 CD 8F E2 7A B7
0280  CA 49 E2 01 08 E3 CD 50 E1 CD 66 E1 C3 49 E2 C5
0290  CD 10 E0 4F CD 79 E1 DA C6 E2 CD 9A E1 47 CD 10
02A0  E0 4F CD 79 E1 D2 BF E2 CD AD E2 C1 C9 01 17 E3
02B0  C3 50 E1 FE 01 C0 7B B7 C0 CD AD E2 C3 7D E0 B0
02C0  4F 82 57 79 C1 C9 CD AD E2 C3 49 E2 DB ED E6 02
02D0  CA CC E2 DB EC E6 7F C9 F5 DB ED E6 01 CA D9 E2
02E0  79 D3 EC F1 C9 0D 0A 43 50 4D 20 32 2E 30 00 0D
02F0  0A 4C 42 4C 20 5A 38 30 20 4D 69 6E 69 2D 4D 6F
0300  6E 69 74 6F 72 0D 0A 00 43 68 65 63 6B 73 75 6D
0310  20 45 72 72 6F 72 00 0D 0A 45 4F 46 20 4F 52 20
0320  42 41 44 20 48 45 58 00 FF FF FF FF FF FF FF FF
0330  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF
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0340  FF FF 03 41 43 4B 06 00 03 41 4C 30 F0 00 03 41
0350  4C 31 00 00 05 41 4C 4C 30 30 8D DB 05 41 4C 4C
0360  30 31 F8 DB 05 41 4C 4C 30 32 63 DC 05 41 4C 4C
0370  30 33 CE DC 05 41 4C 4C 30 34 39 DD 05 41 4C 4C
0380  30 35 A4 DD 05 41 4C 4C 30 36 0F DE 05 41 4C 4C
0390  30 37 7A DE 05 41 4C 4C 30 38 E5 DE 05 41 4C 4C
03A0  30 39 04 DF 05 41 4C 53 49 5A 6B 00 02 42 43 00
03B0  00 05 42 44 49 53 4B 00 D7 04 42 44 4F 53 06 C4
03C0  03 42 45 4C 07 00 05 42 45 58 49 54 5D D3 04 42
03D0  49 41 53 00 88 04 42 49 4F 53 00 D2 03 42 4C 4D
03E0  0F 00 05 42 4C 4F 4F 50 18 D3 05 42 4F 4F 54 45
03F0  03 D2 04 42 4F 4F 54 00 D3 03 42 53 48 04 00 03
0400  C3 ED DA C3 8B DA C3 33 DB C3 3B DB C3 46 DB C3
0410  59 DB C3 7A DB C3 7D DB C3 A6 DB C3 90 DB C3 A8
0420  DB C3 AD DB C3 B2 DB C3 BE DB C3 EE DB C3 51 DB
0430  C3 B8 DB 53 DA 00 00 00 00 00 00 4A DD 6D DA 08
0440  DE CA DD 53 DA 00 00 00 00 00 00 4A DD 7C DA 18
0450  DE E9 DD 01 07 0D 13 19 05 0B 11 17 03 09 0F 15
0460  02 08 0E 14 1A 06 0C 12 18 04 0A 10 16 1A 00 03
0470  07 00 F2 00 3F 00 C0 00 10 00 02 00 1A 00 03 07
0480  00 F2 00 3F 00 C0 00 10 00 02 00 31 00 01 0E 00
0490  CD 90 DB CD 80 DB 06 2C 0E 05 16 01 1E 1A 21 00
04A0  C3 D5 C5 E5 CD AD DB E1 E5 EB 26 00 69 29 29 29
04B0  29 29 29 29 19 22 41 00 CD BE DB B7 C2 8B DA E1
04C0  C1 3E 04 81 4F 05 CA EC DA D1 7B B9 D2 A1 DA 14
04D0  4A 3E 04 BA D2 A1 DA 3E 01 32 C2 DC 57 4F 3E 1A
04E0  B8 DA E5 DA 78 5F 21 00 D0 C3 A1 DA D1 3E C3 32
04F0  00 00 21 03 DA 22 01 00 01 80 00 CD B2 DB AF 32
0500  07 C4 3E C3 32 05 00 21 06 CC 22 06 00 3A C7 DC
0510  B7 CA 2C DB AF 32 C7 DC 32 04 00 3A C8 DC 32 07
0520  C4 4F 06 00 21 C9 DC 11 08 C4 ED B0 3A 04 00 4F
0530  C3 00 C4 DB ED E6 02 C8 3E FF C9 CD 33 DB CA 3B
0540  DB DB EC E6 7F C9 DB ED E6 01 CA 46 DB 79 D3 EC
0550  C9 DB BD E6 01 C8 3E FF C9 CD 6F DB FE 0D C0 C5
0560  0E 05 CD 6F DB DB BD E6 02 28 FA DB BC C1 C9 DB
0570  BD E6 01 CA 6F DB 79 D3 BC C9 C3 46 DB 3E 1A C9
0580  3E 01 D3 07 3E 21 CD 63 DC 3E 0D CD 63 DC 18 16
0590  21 00 00 79 FE 02 D0 32 40 00 6F 26 00 29 29 29
05A0  29 11 33 DA 19 C9 0E 00 79 32 C2 DC C9 79 32 C4
05B0  DC C9 69 60 22 41 00 C9 EB 09 6E 26 00 C9 CD 28
05C0  DC C2 22 DC 06 0A 3E 03 CD 63 DC CA D5 DB 05 C2
05D0  C6 DB C3 22 DC 2A 41 00 06 80 3E 40 D3 06 DB 07
05E0  77 23 3E 41 D3 06 05 C2 DA DB AF D3 06 C9 CD 28
05F0  DC C2 22 DC DB 07 CB 67 C2 A2 DC 2A 41 00 06 80
0600  7E 23 D3 07 3E 31 CD 63 DC 05 C2 00 DC 06 08 3E
0610  05 CD 63 DC 3E 07 CD 63 DC DB 07 E6 08 C8 05 C2
0620  0F DC CD 61 DC 3E 01 C9 3E 0B D3 06 AF D3 06 DB
0630  07 CB 77 3E 00 CC 63 DC 3A 40 00 0F 0F 47 3A C4
0640  DC B0 D3 07 3E 21 CD 63 DC 3A C2 DC FE 4D 30 69
0650  D3 07 3E 11 CD 63 DC 3E 09 CD 63 DC 3E 09 C3 63
0660  DC 3E 0B F5 D3 06 AF D3 06 DB 07 CB 6F C2 87 DC
0670  CB 77 CA 80 DC CB 47 C2 69 DC F1 DB 07 CB 5F C9
0680  C5 01 16 DD C3 8B DC C5 01 D3 DC CD 1C E0 CD 3B
0690  DB FE 03 CA 8B DA CD 1F E0 3E 0B D3 06 C1 F1 C3
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06A0  63 DC C5 01 E7 DC CD 1C E0 CD 3B DB 4F CD 46 DB
06B0  FE 59 C1 CA EE DB C3 22 DC 01 2C DD CD 1C E0 C3
06C0  22 DC 00 00 00 00 00 01 0A 53 50 45 45 44 20 39
06D0  36 30 00 0D 0A 07 43 6C 6F 73 65 20 44 72 69 76
06E0  65 20 44 6F 6F 72 00 0D 0A 07 57 72 69 74 65 20
06F0  50 72 6F 74 65 63 74 65 64 2C 20 52 65 74 72 79
0700  3F 20 00 0D 0A 07 49 6C 6C 65 67 61 6C 20 44 72
0710  69 76 65 0D 0A 00 0D 0A 07 54 75 72 6E 20 6F 6E
0720  20 44 69 73 6B 20 44 72 69 76 65 00 0D 0A 07 49
0730  6C 6C 65 67 61 6C 20 74 72 61 63 6B 20 73 65 65
0740  6B 20 28 3E 37 36 29 0D 0A 00
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